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Measurement of human eye aberrations using an optical simulator based on pyramid wavefront sensor

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INTRODUCTION

High resolution imaging of retinal cell can do benefit to the early diagnosis of retinopathy inducing retinal vascular disease, macular disease and detached retinas. The pyramid wavefront sensor (PWS) used by astronomers to measure wavefront aberrations due to atmospheric turbulence is becoming a hot spot. Because of its advantages of sampling in pupil and adjustable dynamic range, it was introduced into ophthalmic optics and showed its huge practical value.

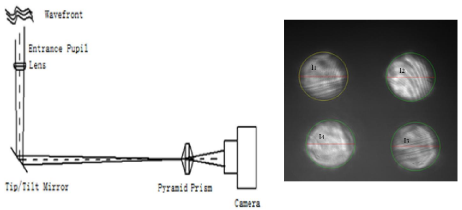

Fig.1 Left: A schematic diagram of a pyramid wavefront sensor. Right: sub-pupil images .

PRINCIPLE

The relationship between wavefront slope with S_x and S_y is implied by formula (3). Wavefront aberrations can be reconstructed based on the Zernike polynomial.

$$S_x(i,j) = \frac{I_1(i,j)+I_4(i,j)-I_2(i,j)-I_3(i,j)}{I_1(i,j)+I_2(i,j)+I_3(i,j)+I_4(i,j)} \quad (1)$$

$$S_y(i,j) = \frac{I_1(i,j)+I_2(i,j)-I_3(i,j)-I_4(i,j)}{I_1(i,j)+I_2(i,j)+I_3(i,j)+I_4(i,j)} \quad (2)$$

$$\begin{cases} \frac{\partial W(i,j)}{\partial x} \propto \alpha \cdot \sin\left[\frac{\pi}{2} S_x(i,j)\right] \\ \frac{\partial W(i,j)}{\partial y} \propto \alpha \cdot \sin\left[\frac{\pi}{2} S_y(i,j)\right] \end{cases} \quad (3)$$

$$W(r) = \Sigma_j^n a_j Z_j(r) \quad (4)$$

METHODS

We design an optical simulator shown as Fig. 2. The light generated by a slit lamp passes through a serial of converagence, shrinking and folding from L1-L3 lenslets and M1 mirrors, and is propagated to M2 and M3 mirrors which are mounted on a movable translation stage.

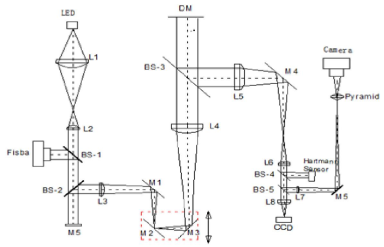

Fig.2 The optical layout of simulator

Next, The reflected beam is collimated by lens L4 and arrives at a 109-channels deformable mirror (DM) which will produce another astigmatism item of human eye aberrations. In order to match the entrance pupil of SHWS and PWS, the following beam's diameter is reduced again by L5 and L6 lens. SHWS plays a role on both calibrating static optical errors of the whole simulator and validating the measurement of PWS.

RESULTS

● **Defocus:** We choose a translating stage with enough large travel range. Meanwhile at each step, PWS captured the correponding sub-pupil image and reconstruct the defocus coefficient.

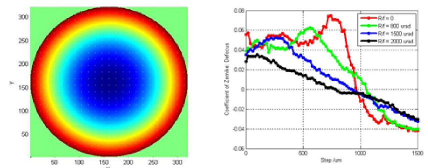

Fig. 3 Left: Phase diagram of defocus expressed with Standard Zernike Polynomial; Right: Reconstructed defocus coefficient relative to travel of translating stage

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● **Astigmatism:** Astigmatism also is main component of human eye aberrations. A 109-channels deformable mirror is utilized to produce astigmatism error.

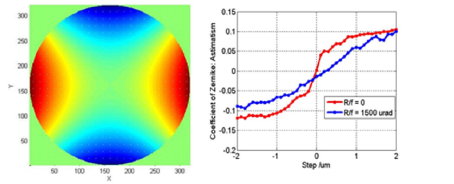

Fig.4 Left: Phase diagram of 0° astigmatism expressed with Standard Zernike Polynomial; Right: Reconstructed astigmatism coefficient relative to astigmatism coefficient which is imposed on deformable mirror.

CONCLUSIONS

- **Defocus and astigmatism items can be detected by pyramid wavefront sensor effectively.**
- **The dynamic measurement range and the linear fitting residuals are both proportional to the modulation amplitude.**
- **The sensitivity is inversely proportional to the modulation amplitude.**

The next work is to build an adaptive optics closeloop system to compensate human eye aberrations rapidly. A modal eye as a measurement target will be inserted the optical path of simulator.